PHYSOR-2004.
The Physics of Fuel Cycles and Advanced Nuclear Systems:Global Developments
April 25-29, 2004, Chicago, IL USA

STRENGTHENING OF PHYSICAL BASE OF NUCLEAR POWER

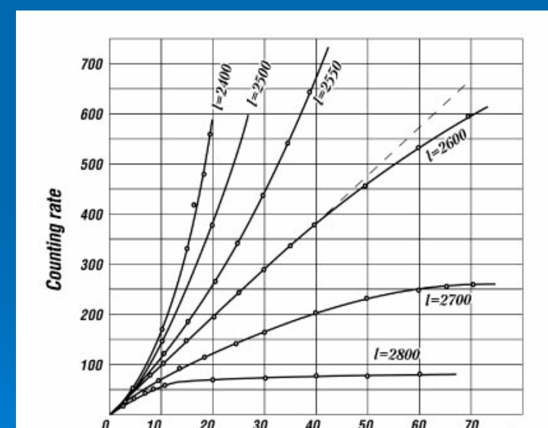
Nikolai N. Ponomarev-Stepnoi

Sergei M. Zaritsky

RRC Kurchatov Institute, Russia

CONTENTS

FIRST CRITICALITY, 25.12.1946

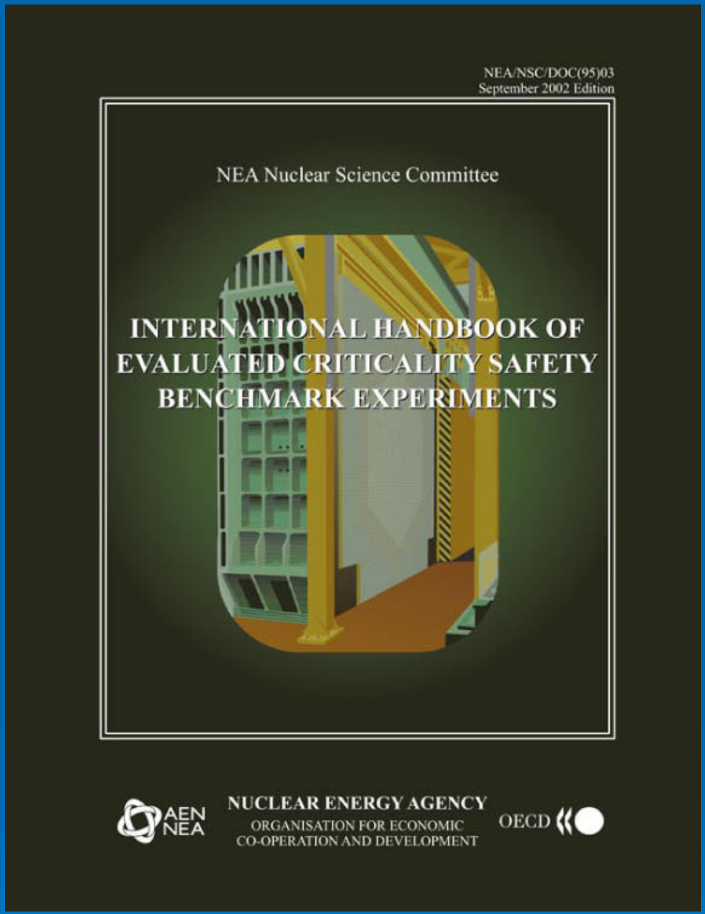


- ***Reactor physics is a base of nuclear power, and strength of this base is a necessary condition of nuclear power successful development.***

- ***After the first nuclear criticality had been reached neutron physics experiments played a crucial role in the creation and improvement of nuclear reactors.***

- ***Most experiments were performed (mainly as a necessary stage of reactor design) in the nuclear power "golden age" in 60s and 70s of 20th century, when most of the total of over thousand nuclear reactors have been created worldwide.***

STRENGTHENING OF PHYSICAL BASE OF NUCLEAR POWER



12 countries,

About 400 series of experiments (evaluations),

3000 critical and subcritical configurations,

Russian contribution is about 40% (for systems with ^{235}U of high and intermediate enrichment – 60%)

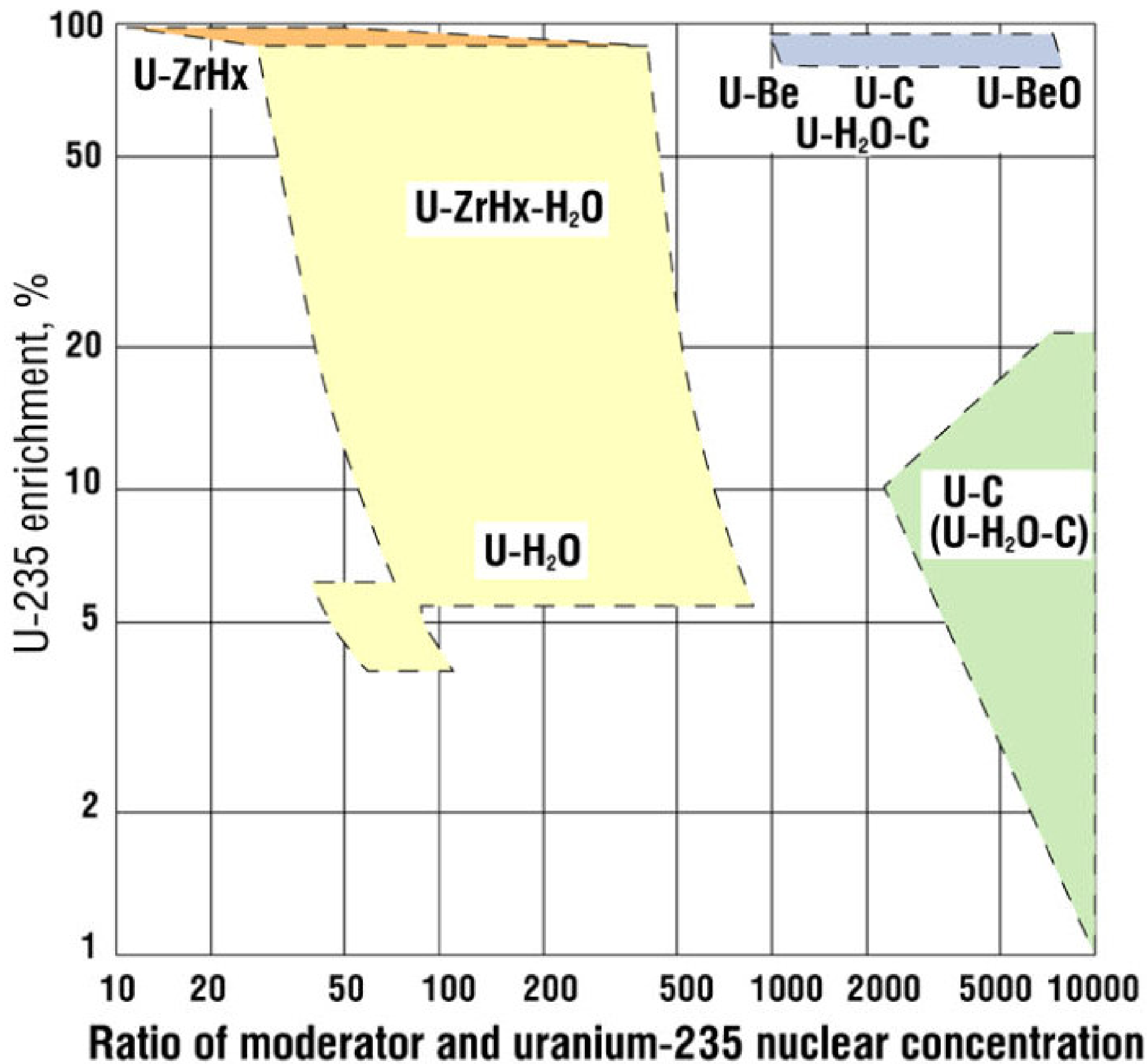
RRC KURCHATOV INSTITUTE

- **Practically all Russian basic critical experiments for power reactors were performed in RRC Kurchatov Institute and Institute of Physics and Power Engineering (IPPE).**

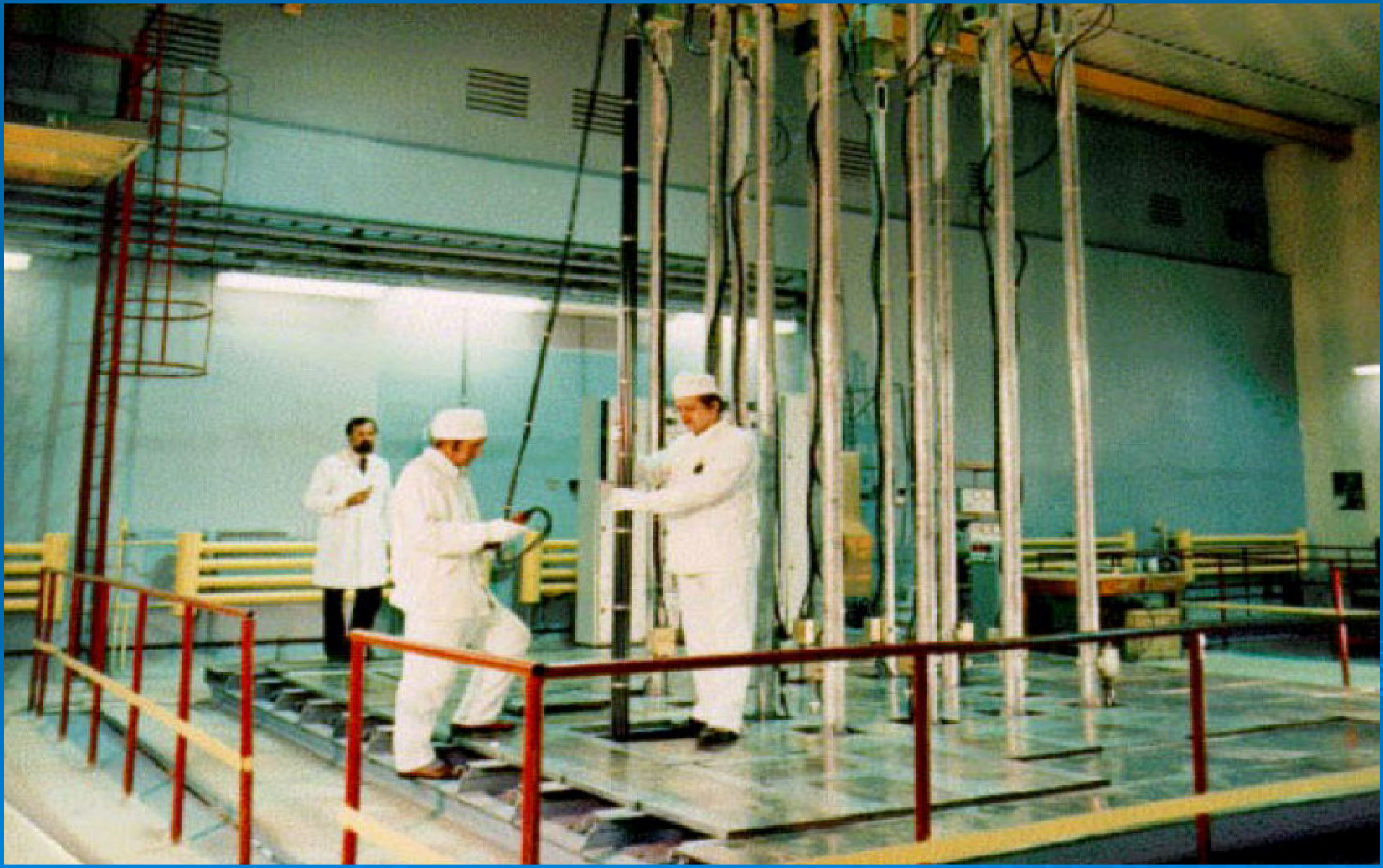
KURCHATOV INSTITUTE – MANY HUNDREDS OF EXPERIMENTS:

- *VVER critical facilities (P, SK-Phys, VVER-1000)*
- *Graphite reactors critical facilities (ASTRA, GROG, RBMK)*
- *Space reactors NARCISS critical facility*
- *Sea reactors critical facilities (SF-1, SF-7, DELTA, KVANT).*

RANGE OF ENRICHMENT AND MODERATOR CHARACTERISTICS FOR CRITICAL EXPERIMENTS IN RRC KURCHATOV INSTITUTE

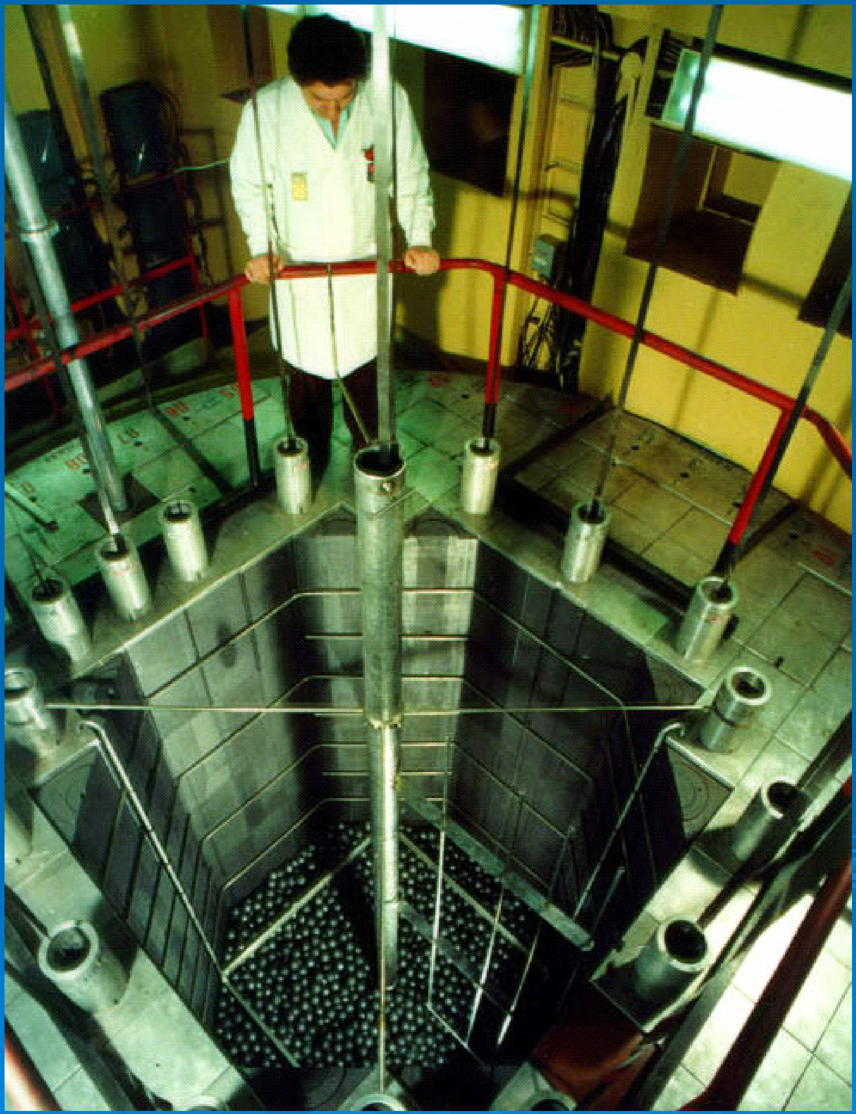


RBMK CRITICAL ASSEMBLY



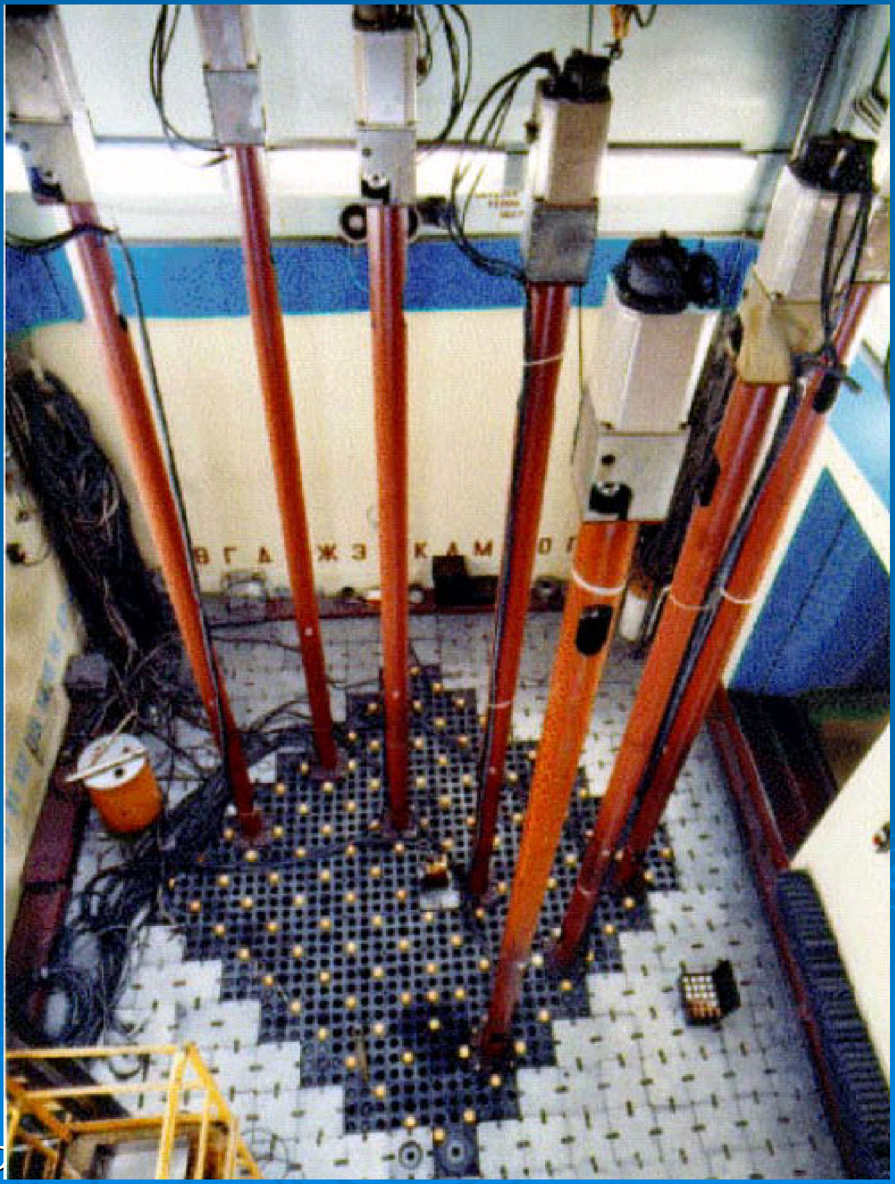
RRC KURCHATOV
INSTITUTE

ASTRA FACILITY



RRC KURCHATOV INSTITUTE

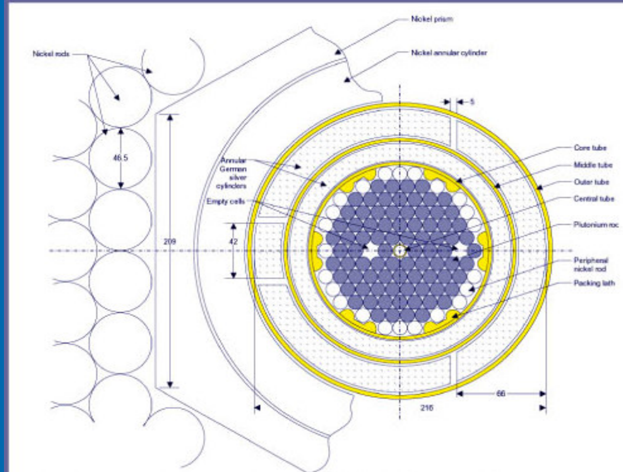
GROG FACILITY



INSTITUTE OF PHYSICS AND POWER ENGINEERING (IPPE):

- *The BFS-1 and BFS-2 critical facilities – an unique experimental facilities for investigations of fast reactor physics, including burning actinides and weapon-grade plutonium utilization (BFS-2 - the world's largest fast critical facility)*
- *MATR-2 critical facility – high-temperature high-pressure uranium-water facility.*

BFS-1 CRITICAL FACILITY IN IPPE

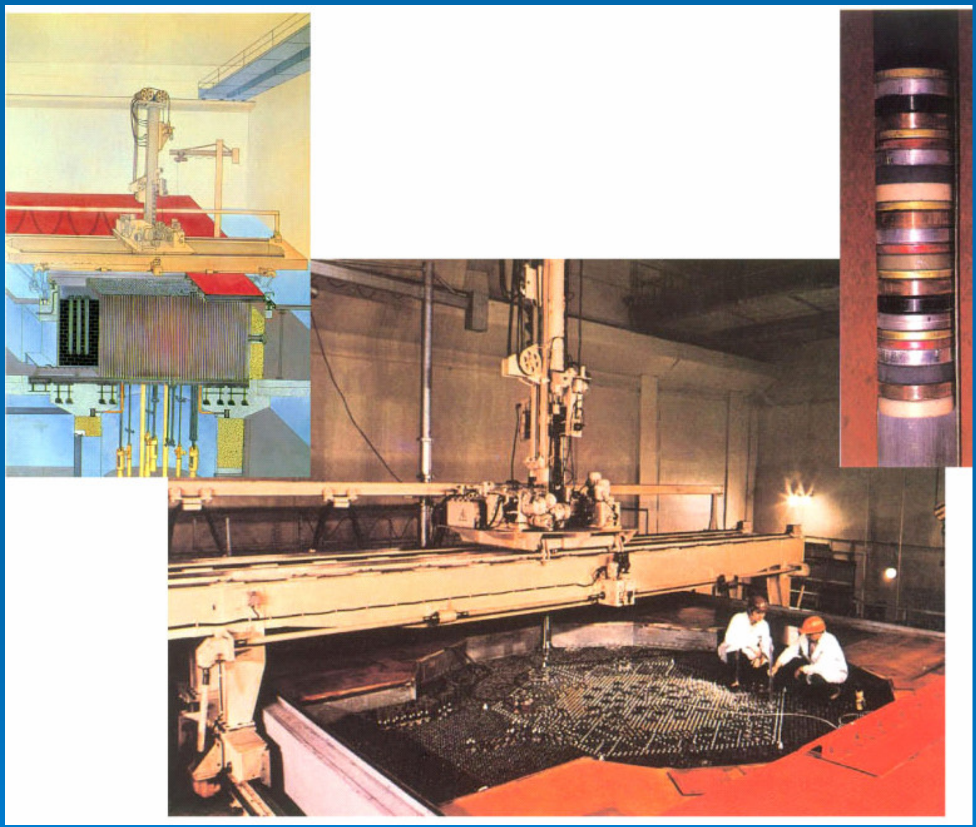


Critical Assembly with Plutonium rods

Experiments for:

- **fast neutron systems**
- **uranyl nitrate solutions (reprocessing facilities)**
- **space and see reactors**

BFS-2 CRITICAL FACILITY IN IPPE

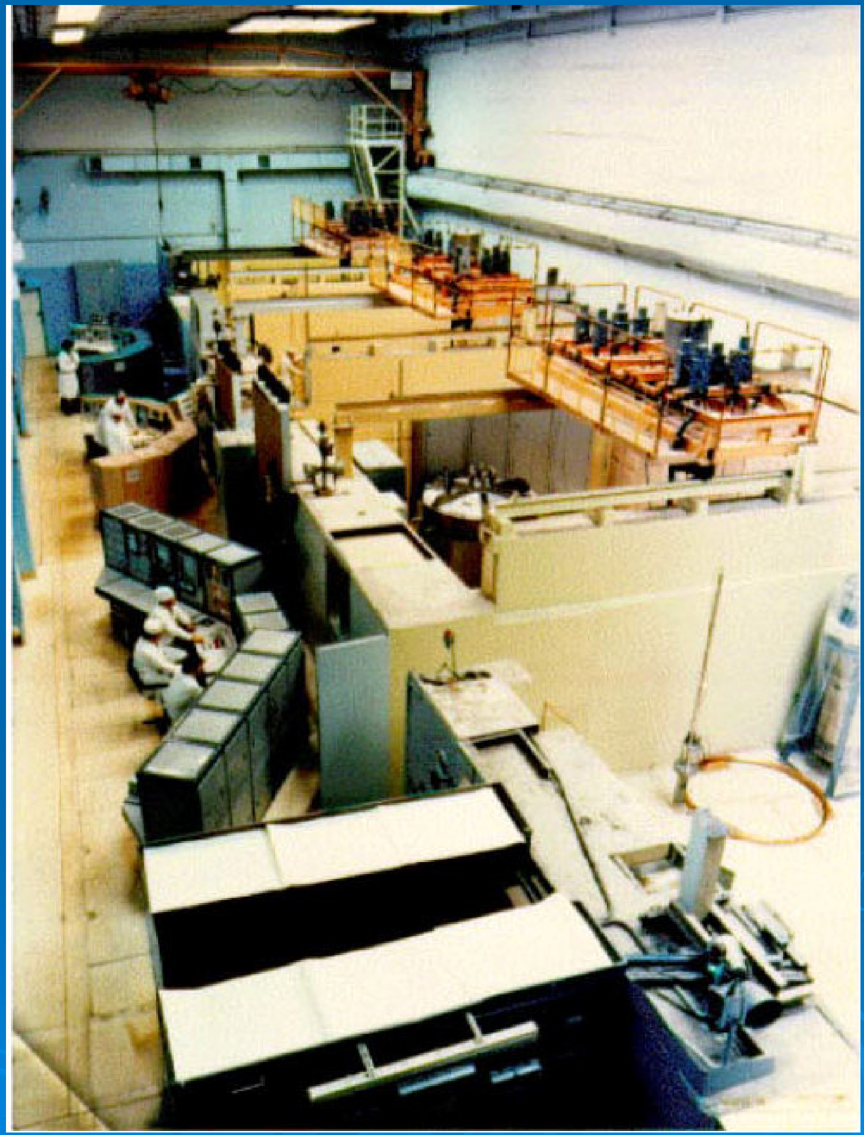


Directions of works:

- **BN-600 reactor core with MOX-fuel**
- **BN-800**
- **lead coolant reactors**
- **actinides transmutation**
- **neutron data for lead and bismuth**

- ***Kurchatov Institute and IPPE still preserve capabilities for conducting the reactor experiments: qualified specialists, nuclear fuel of a wide range of compositions, forms and enrichment, facilities, equipment, etc.***
- ***Series of experimental programs were performed in the last years, including those ordered by foreign laboratories.***

Russian Nuclear Centres Still Preserve the Capabilities for New Critical Experiments



RRC KURCHATOV INSTITUTE

- ***Today's situation:***

  Only restricted experimental modeling of reactors is possible due to financial problems

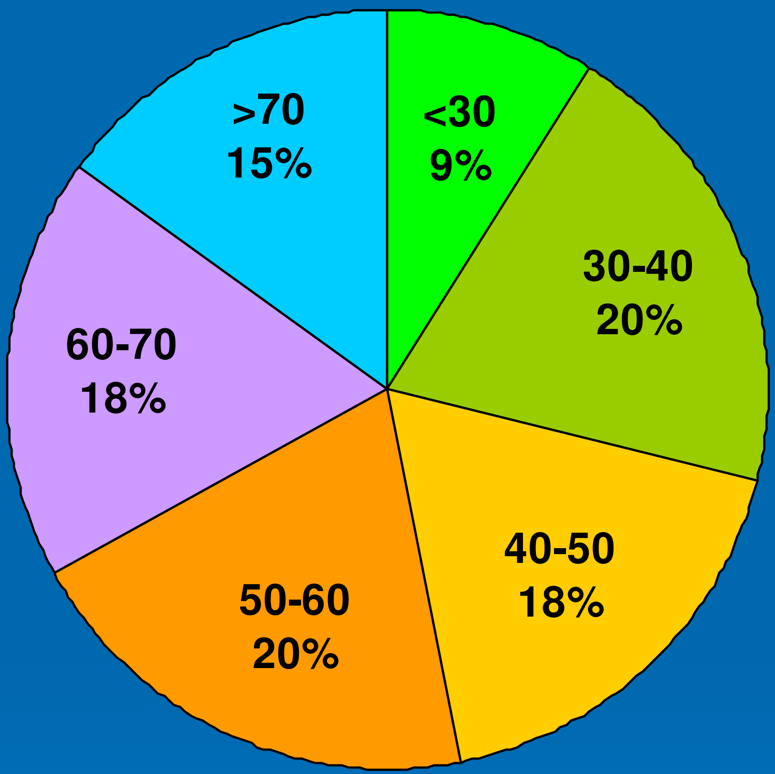
- **Today's situation :**

  The average age of reactor scientists increases, especially in experimental labs.

RRC KURCHATOV INSTITUTE

STAFF AGE DISTRIBUTION IN THE REACTOR PHYSICS DEPARTMENT.

AVERAGE AGE - 52



- ***Today's situation*:**
  Rapid evolution of hardware and system software and the following development of mathematical methods and applied codes.

- ***Despite of any progress in calculations the basic experiments will be always necessary for reliable basing of main safety and economics parameters of nuclear reactors.***

Actual applied problems:

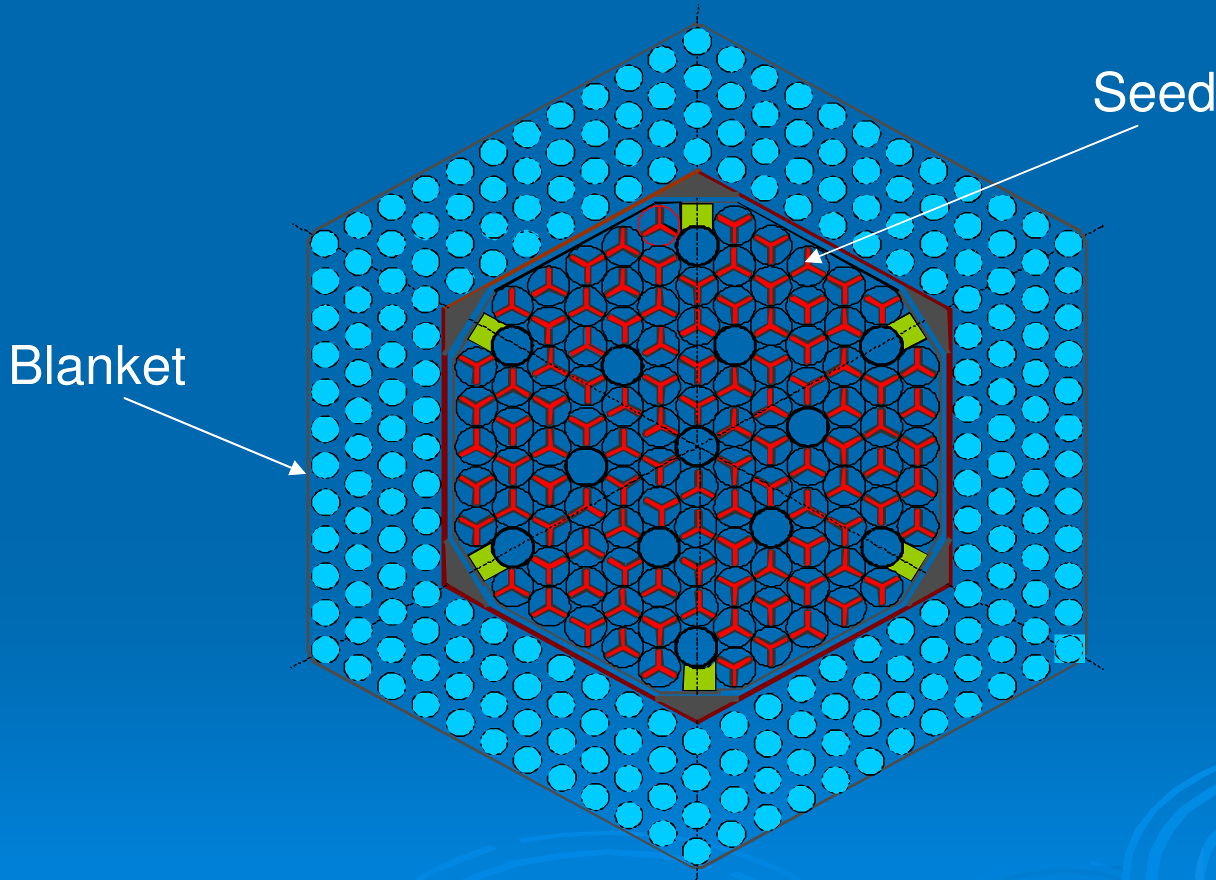
- Support of safety and lifetime extension of operated NPP
- Improvement of fuel cycles and economy of nuclear power
- Investigation and development of innovative concepts

- ***Investigation and development of innovative concepts:***

- ***power reactors of next generation,***
- ***power reactors with MOX fuel,***
- ***non-proliferative reactors with thorium fuel cycle,***
- ***reactors with heavy metal coolant and breeding ratio closed to unity,***
- ***reactors of small and intermediate power for local power consumers and outermost regions,***
- ***reactors and accelerator driven subcritical systems for fuel cycle closing,***
- ***etc***

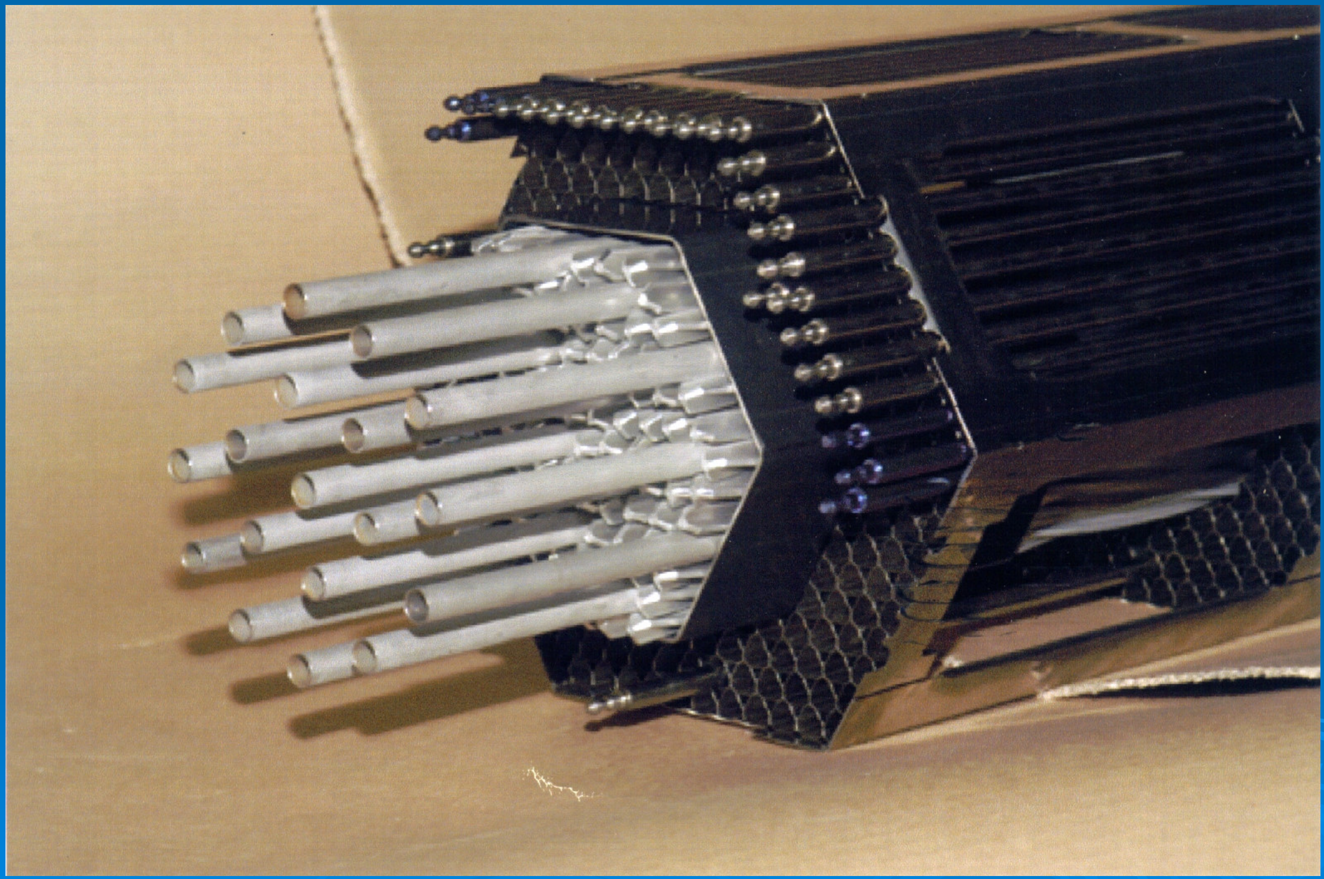
RRC KURCHATOV INSTITUTE

DESIGN OF VVER-T FUEL ASSEMBLY



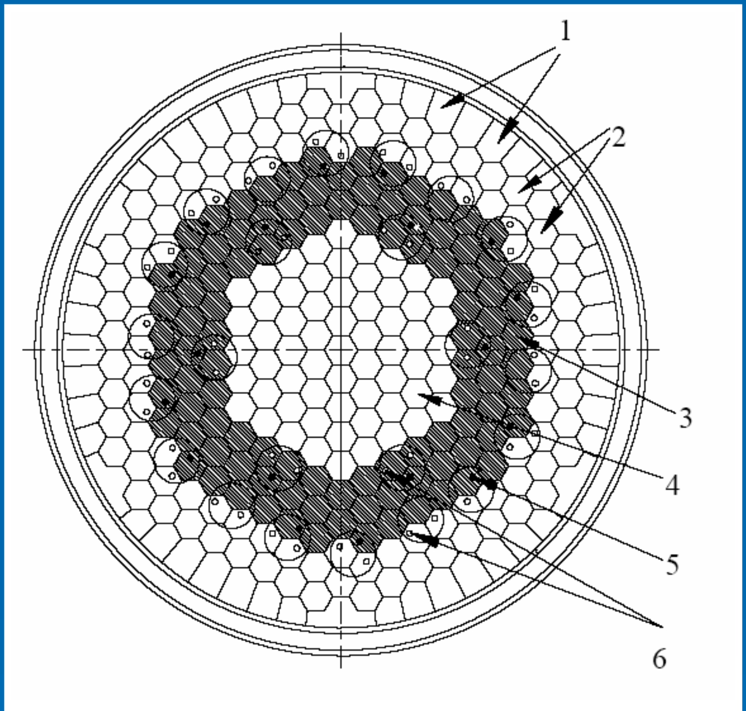
RRC KURCHATOV INSTITUTE

MOCK-UP OF VVER-T SEED/BLANKET FUEL ASSEMBLY

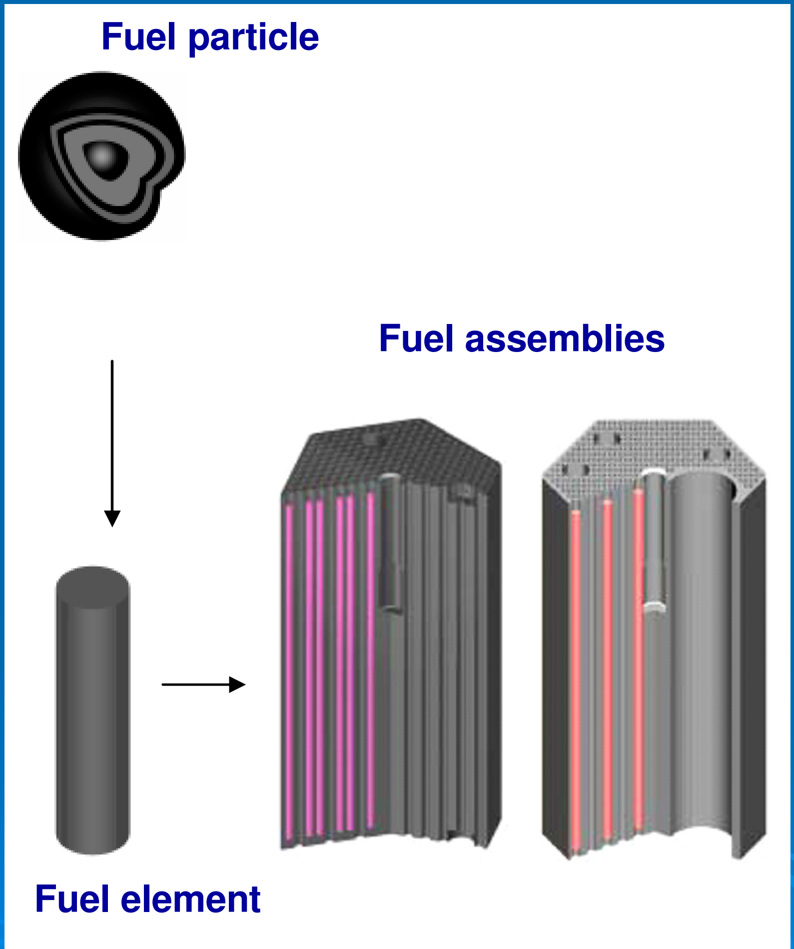


RRC KURCHATOV INSTITUTE

GAS TURBINE MODULAR HELIUM REACTOR (GT-MHR)



1, 2 – outer reflector; 3 – core;
4 – inner reflector; 5 – absorber;
6 – control rod



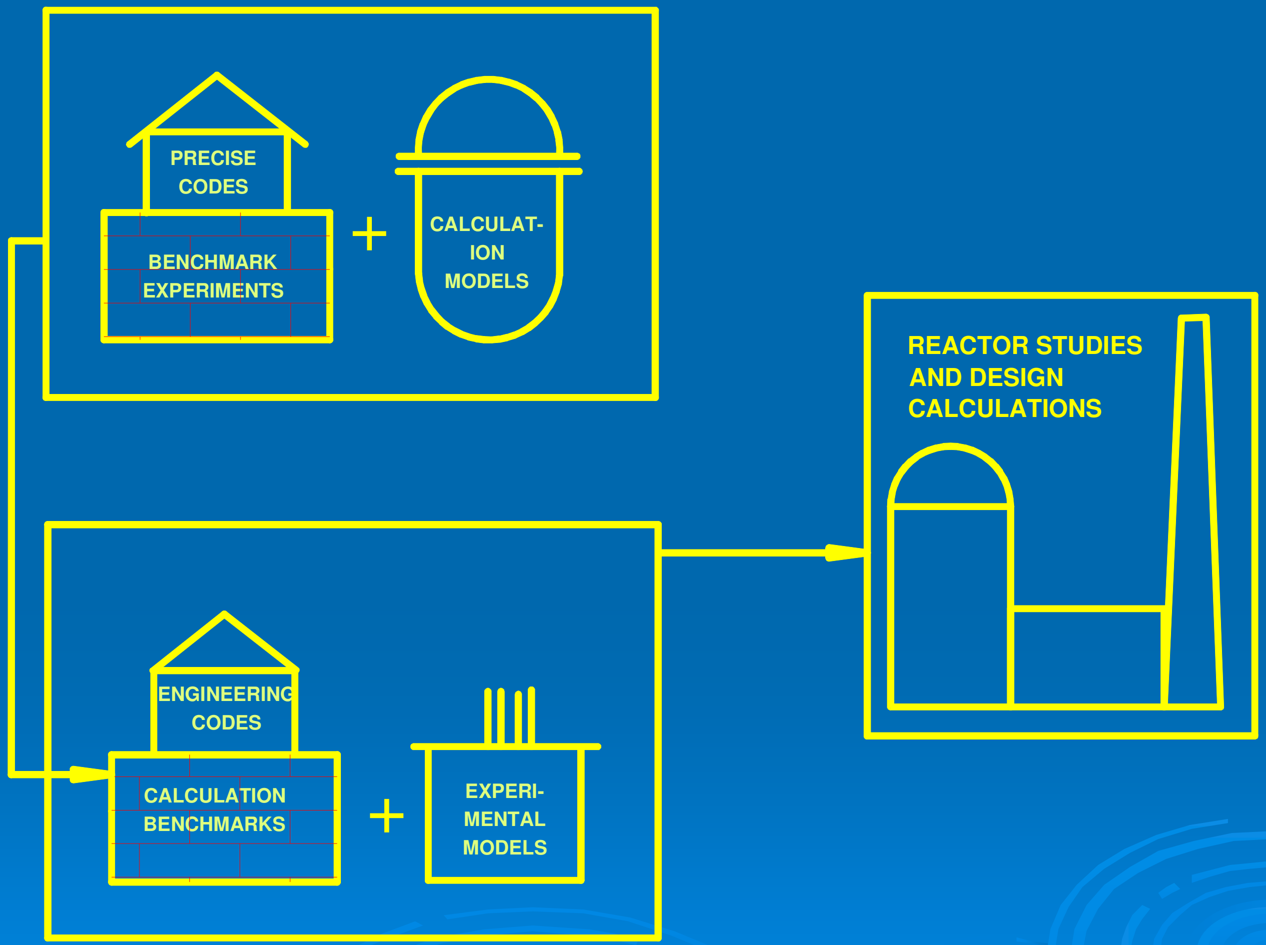
- ***The development of innovative concepts must be based on the modern approaches, which have to be verified by the evaluated "old" benchmark experiments and new ones.***

- ***"Program of strengthening physical base of nuclear power": Foundation for reliable and precise prediction of neutronic parameters of reactor innovative concepts and for improvement of existent reactors and lifetime extension.***

- ***It is strongly necessary to collect, evaluate, and concerve all past experimental experience and data obtained.***

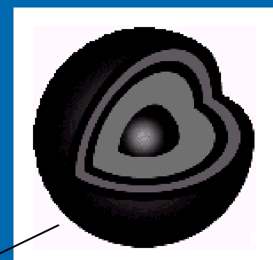
- ***Calculation benchmarks - representative test models of innovative reactors and results of calculations with precise codes, which are validated by all appropriate certified experiments.***

PHYLOSOPHY OF BENCHMARKS USING

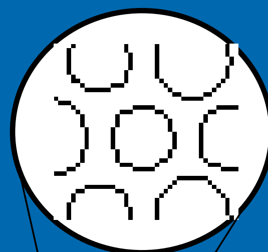


GT-MHR Calculational Benchmarks

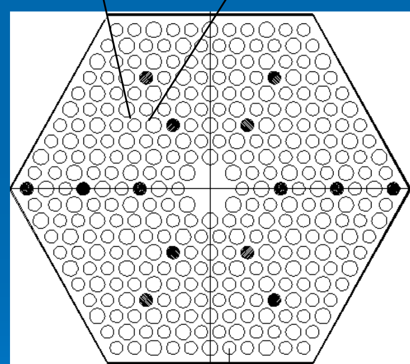
- Elementary cell of a fuel particle

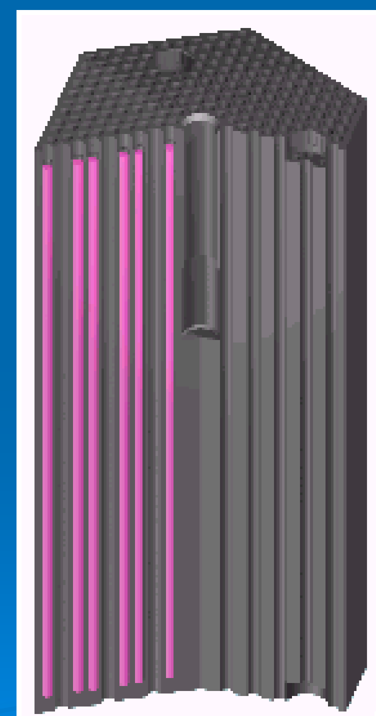


- Fuel compact cell



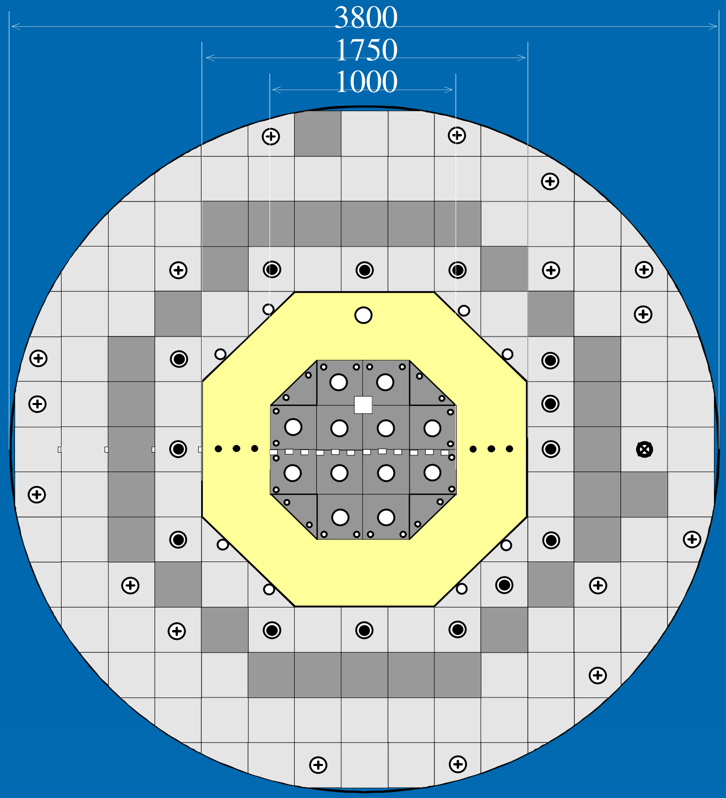
- Fuel block





- Layer of GT-MHR core
- Full-scale GT-MHR reactor model

RRC KURCHATOV INSTITUTE



BENCHMARK EXPERIMENT FOR GT-MHR IN ASTRA FACILITY WITH ANNUAL PEBBLE BED CORE

RRC KURCHATOV INSTITUTE

Code MCU – Monte Carlo universal

Code UNK (cell)

- **Collision probabilities method**
- **1D, 2D**
- **Energy groups:**
  - **24 – fast**
  - **7000 – resolved resonances region**
  - **65 – thermal**

Code UNK GRO (reactor)

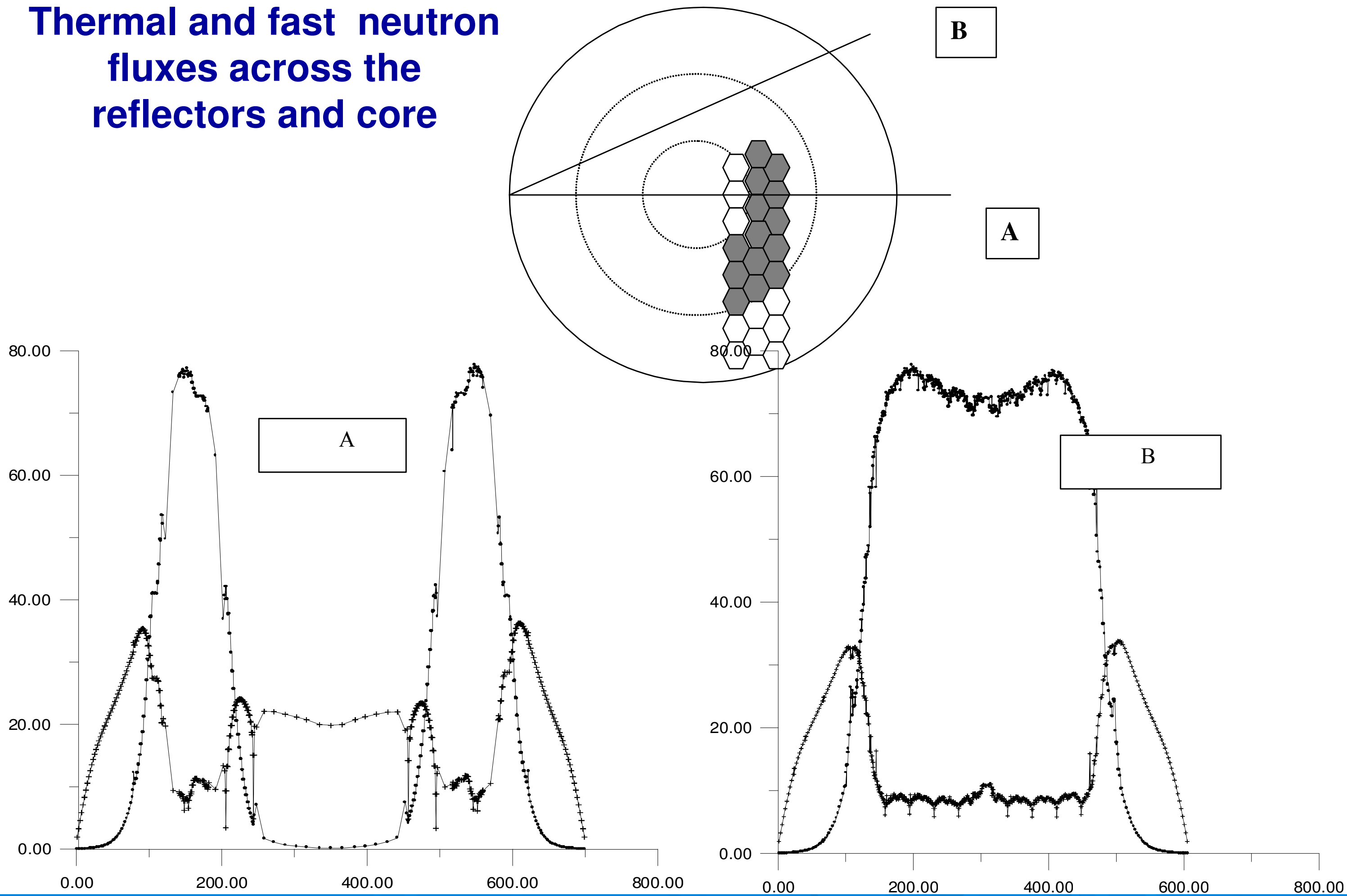
- **Method of characteristics**
- **3D (arbitrary geometry)**

RRC KURCHATOV INSTITUTE

STRENGTHENING OF PHYSICAL BASE OF NUCLEAR POWER

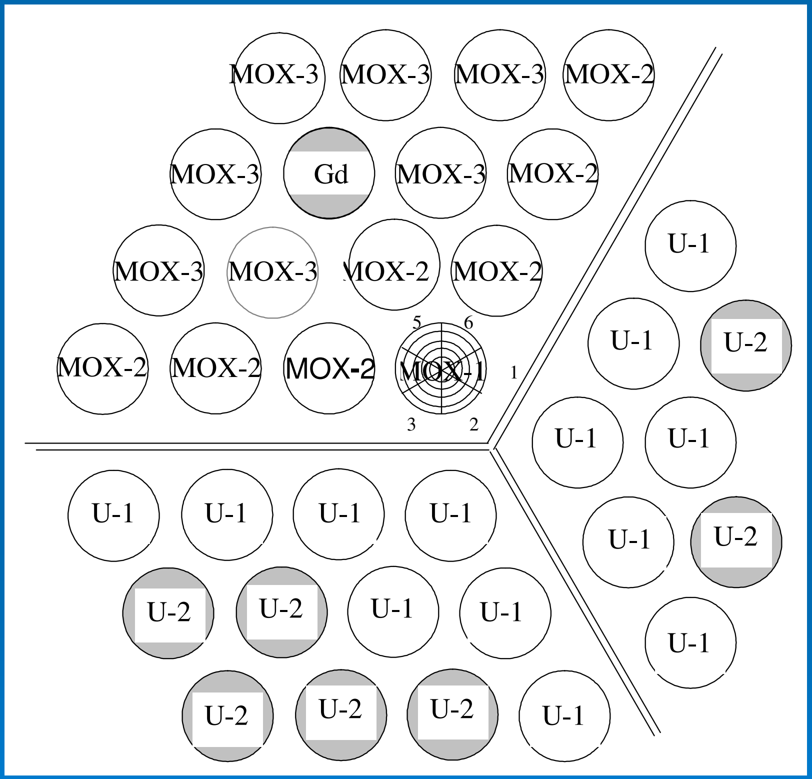
FULL SCALE PIN-BY–PIN TRANSPORT CALCULATIONS OF GT-MHR (UNK CODE)

Thermal and fast neutron fluxes across the reflectors and core

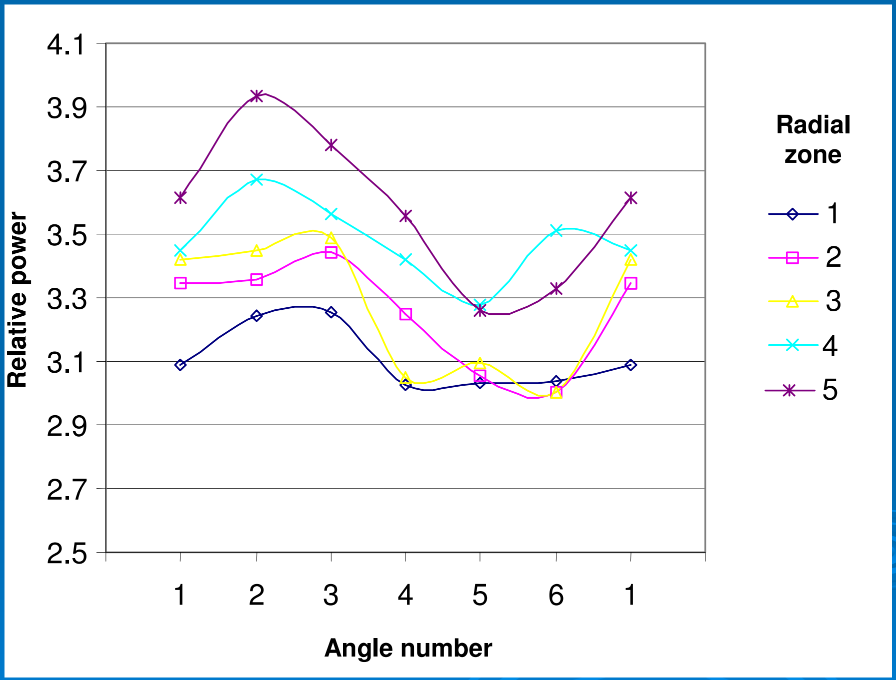


RRC KURCHATOV INSTITUTE

RADIAL-AZIMUTH POWER DISTRIBUTION IN THE CORNER FUEL ELEMENT (VVER-1000)



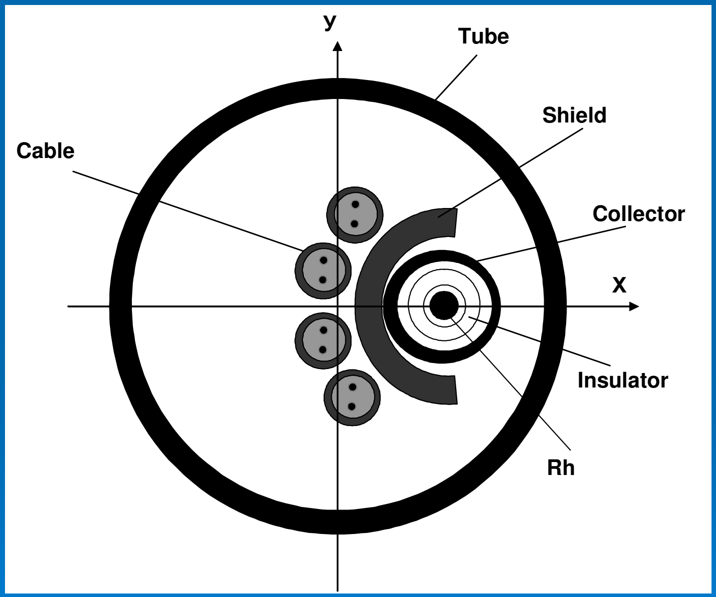
MCU calculation

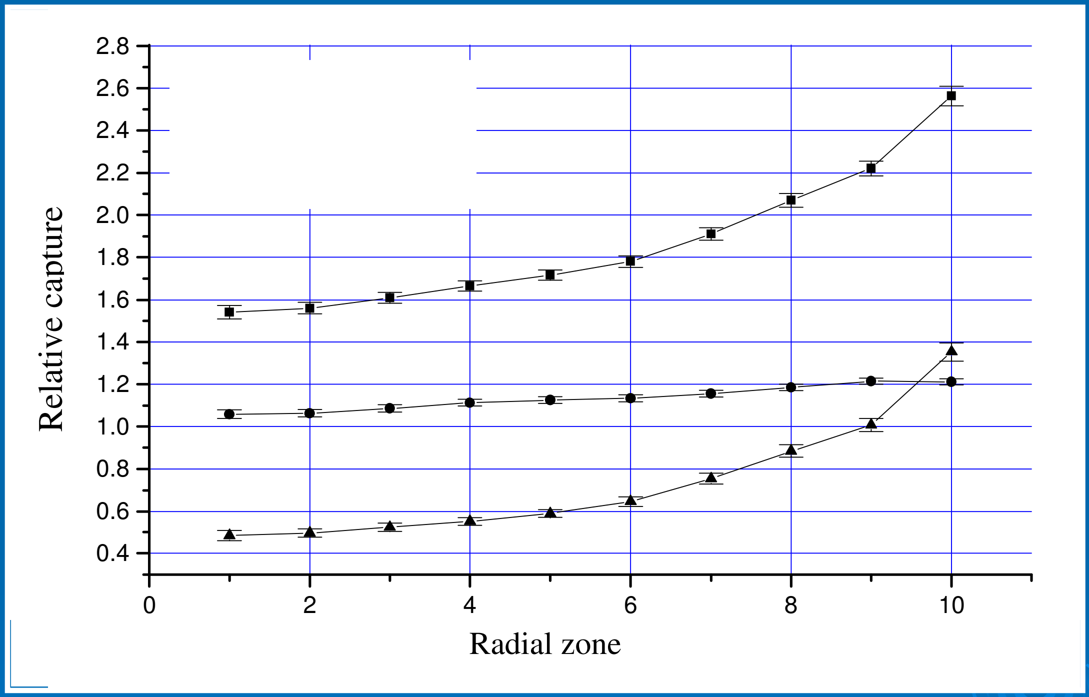


RRC KURCHATOV INSTITUTE

MCU CALCULATION OF Rh SELF-POWERED DETECTOR

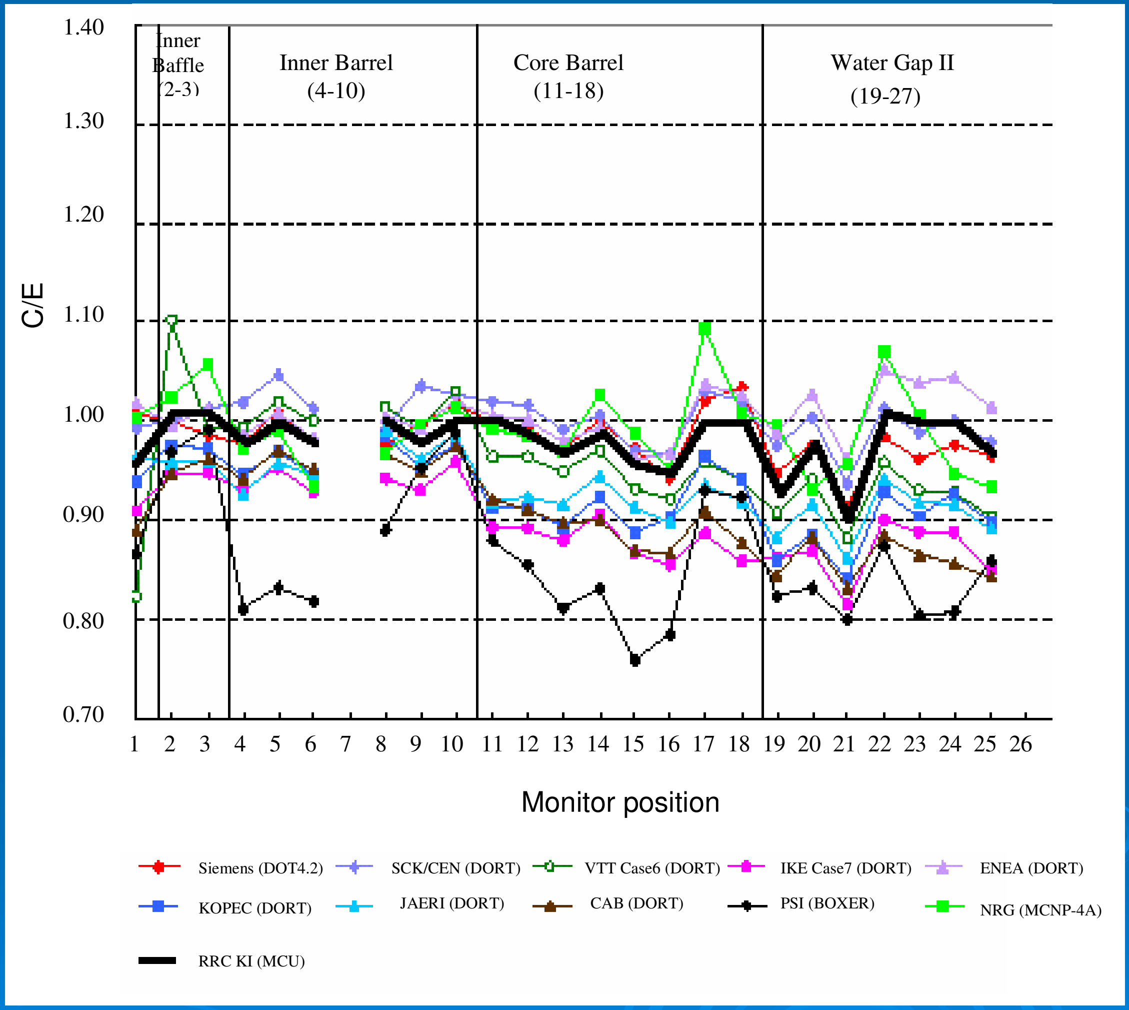
Calculation model of self-powered detector





Radial distribution of neutron capture in Rh wire

VENUS INTERCOMPARISON. RATIO OF CALCULATED (C) AND EXPERIMENTAL (E) VALUES OF EFFECTIVE FISSION NEUTRON FLUX ($^{238}U(n,f)$)



RRC KURCHATOV INSTITUTE

PARALLEL COMPUTATION

- **CODE *LUCKY***

  NEUTRON AND GAMMA TRANSPORT
  3D XYZ GEOMETRY
  DISCRETE ORDINATES

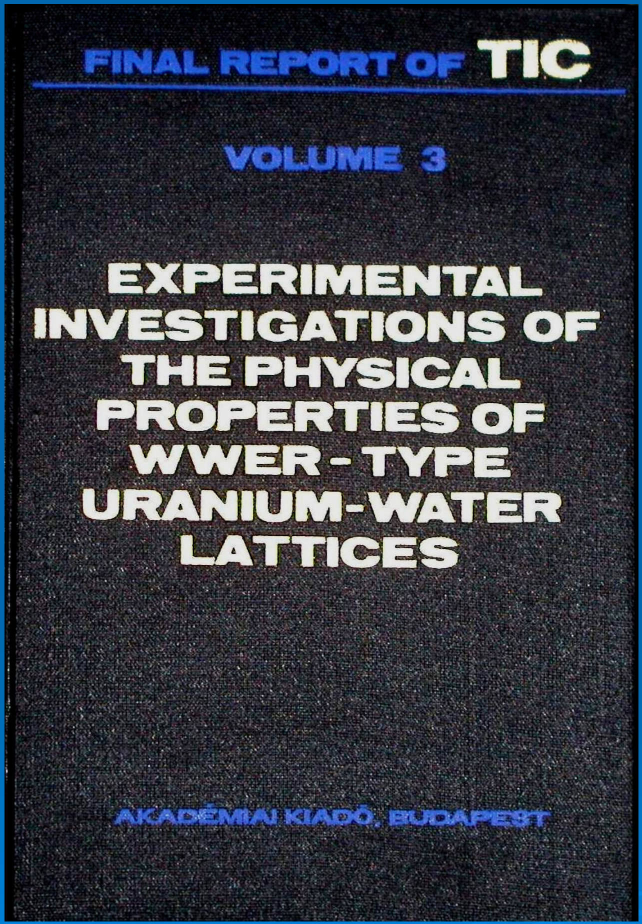
- **COMPUTER MBC-1000M**

  700 PROCESSORS (667 MHz)
  P_3S_8 APPROXIMATION
  40 ENERGY GROUPS
  $2 \cdot 10^8$ MESH INTERVALS

<600 MIN

RRC KURCHATOV INSTITUTE

TEMPORARY INTERNATIONAL COLLECTIVE (TIC) FOR JOINT RESEARCH INTO THE PHYSICS OF WWER-TYPE REACTORS



10 countries

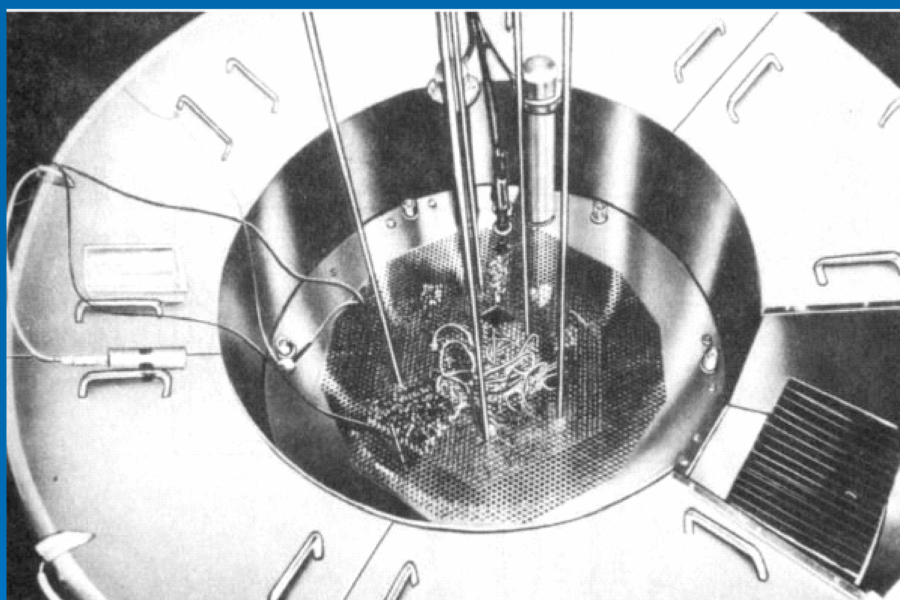
300 experiments

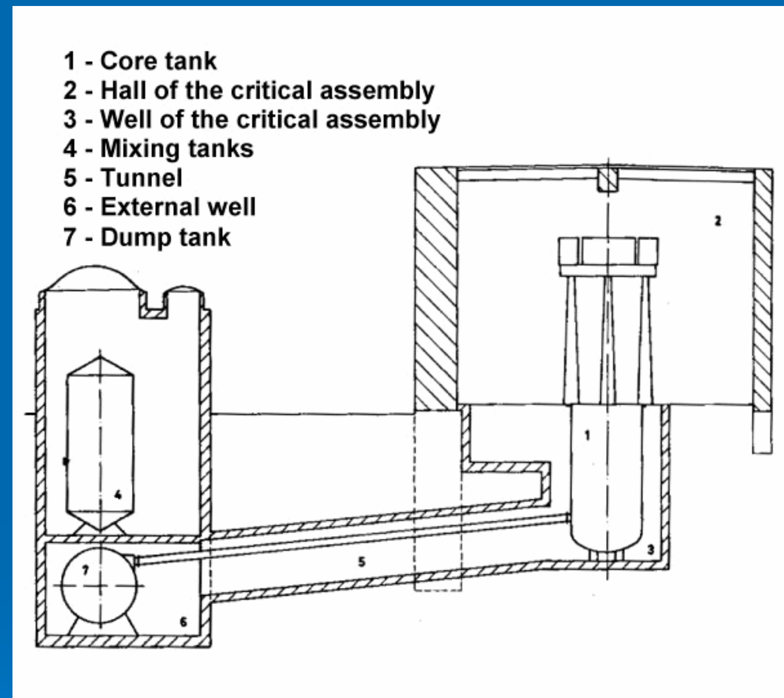
Theoretical studies

Calculation methods

Codes

CRITICAL ASSEMBLY ZR-6 (HUNGARY)

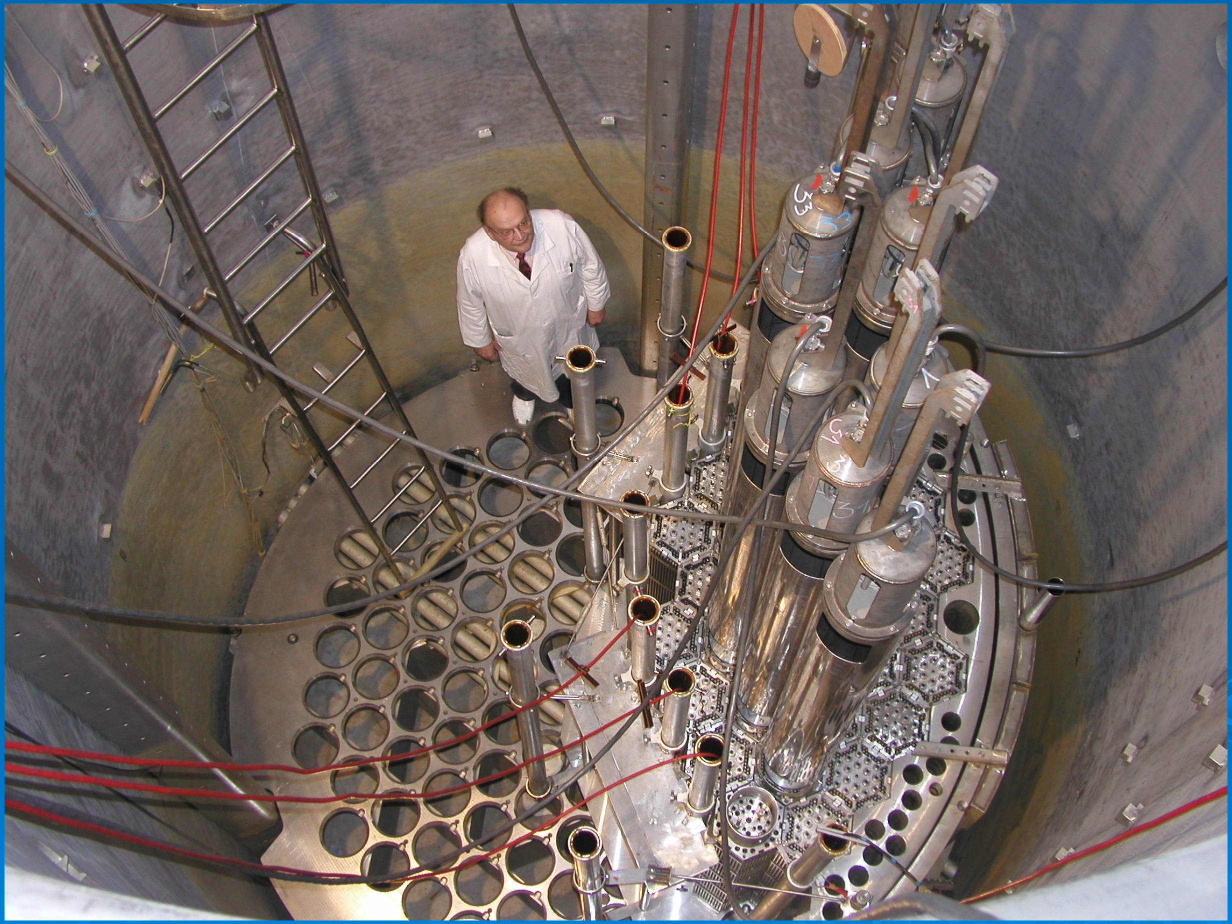




Arrangement of the equipment of the critical assembly

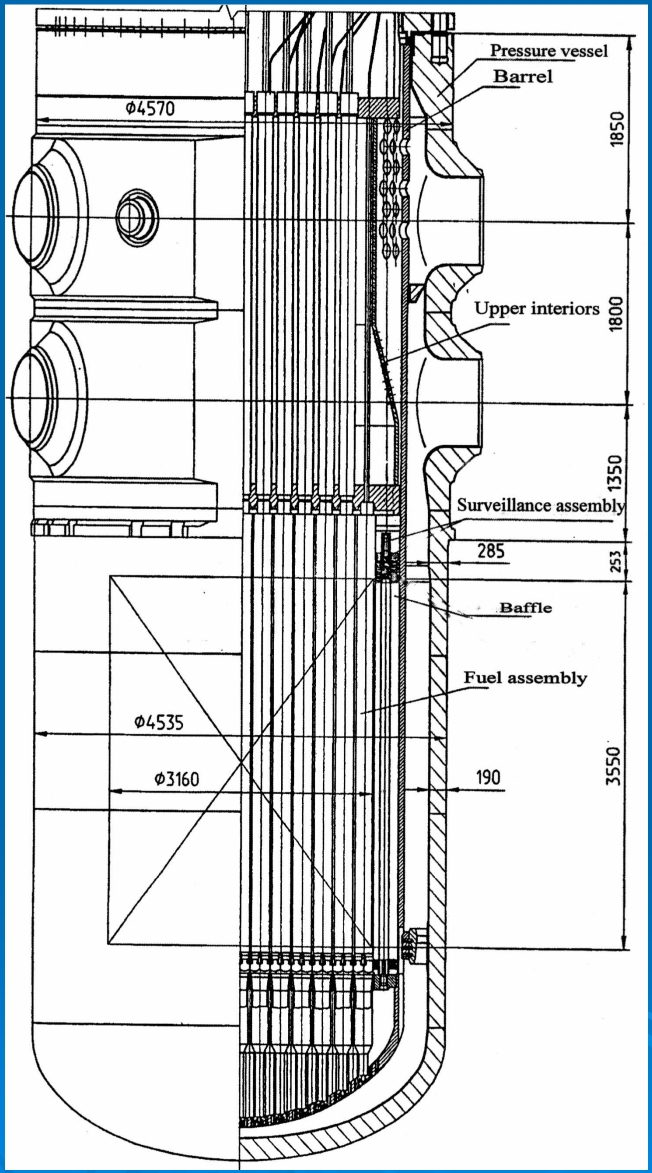
CRITICAL ASSEMBLY LR-0 (Czech Republic)

Full-scale Mock-up of VVER-1000



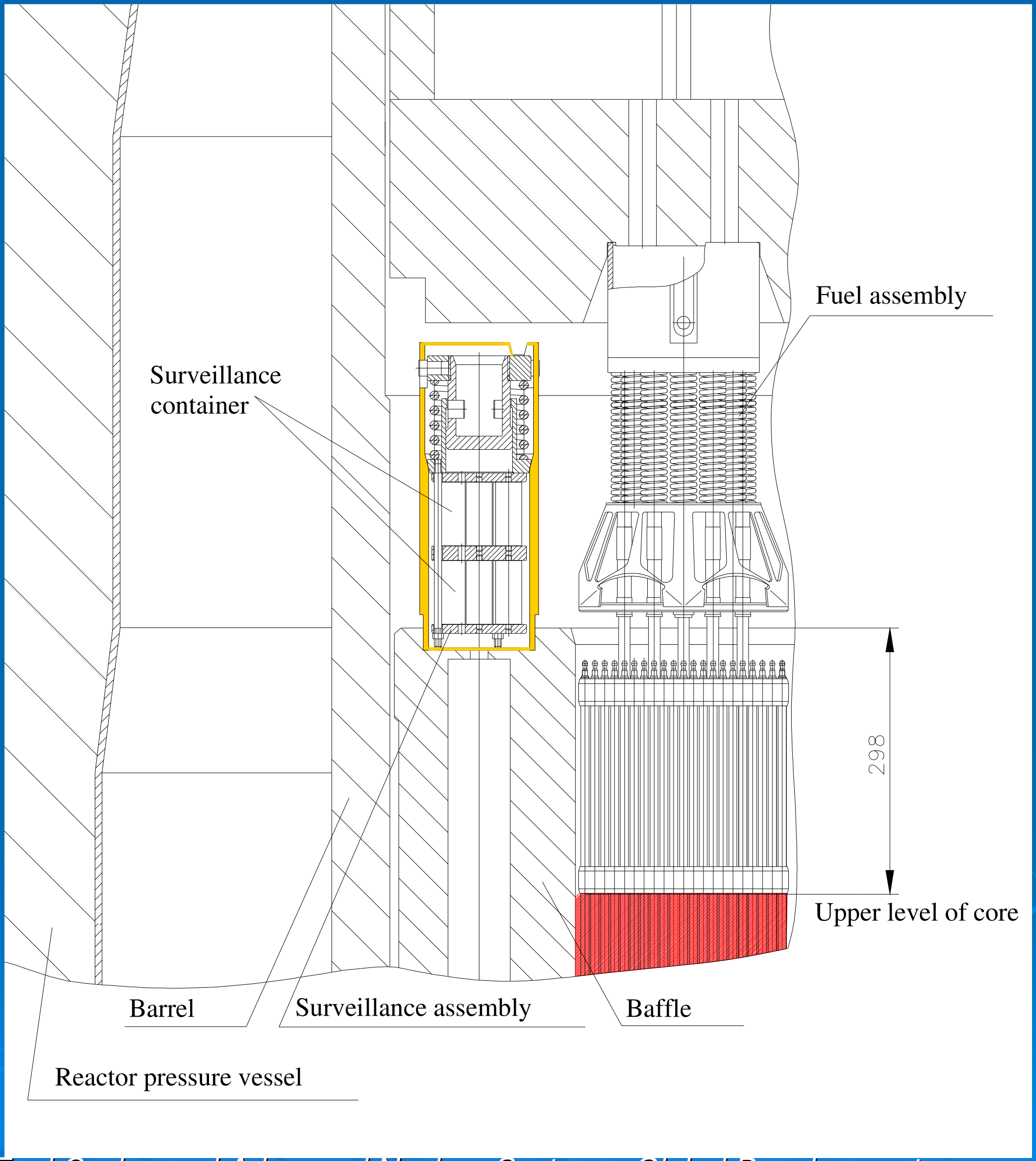
RRC KURCHATOV INSTITUTE

REACTOR VVER-1000



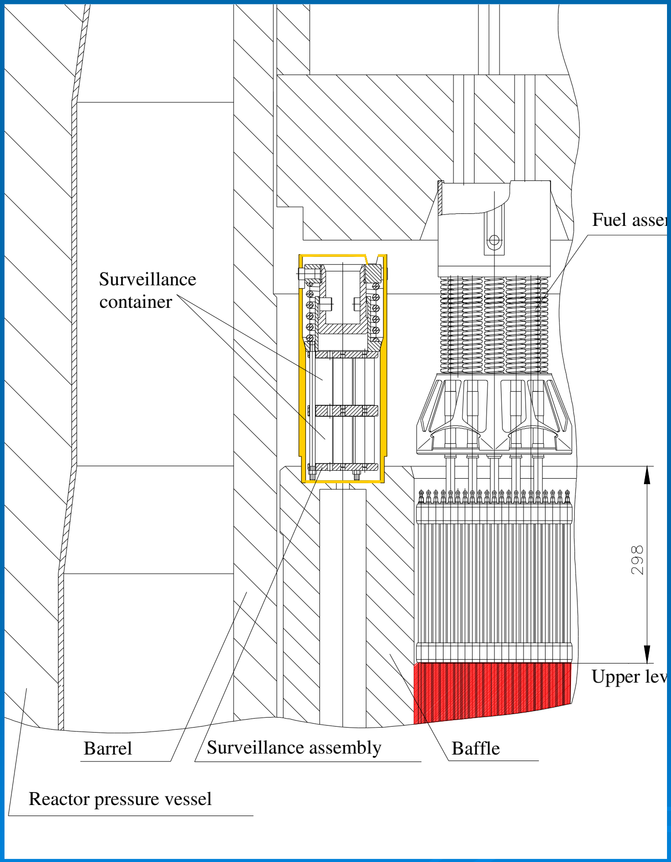
RRC KURCHATOV INSTITUTE

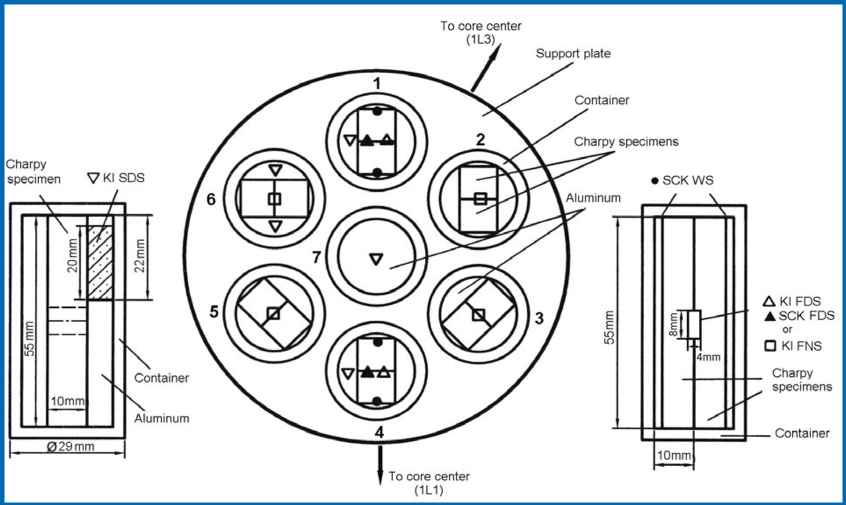
LOCATION OF SURVEILLANCE ASSEMBLY IN VVER-1000



RRC KURCHATOV INSTITUTE

EXPERIMENT ON BALAKOVO-1 VVER-1000 (DOSIMETRY OF SURVEILLANCE SPECIMENS)

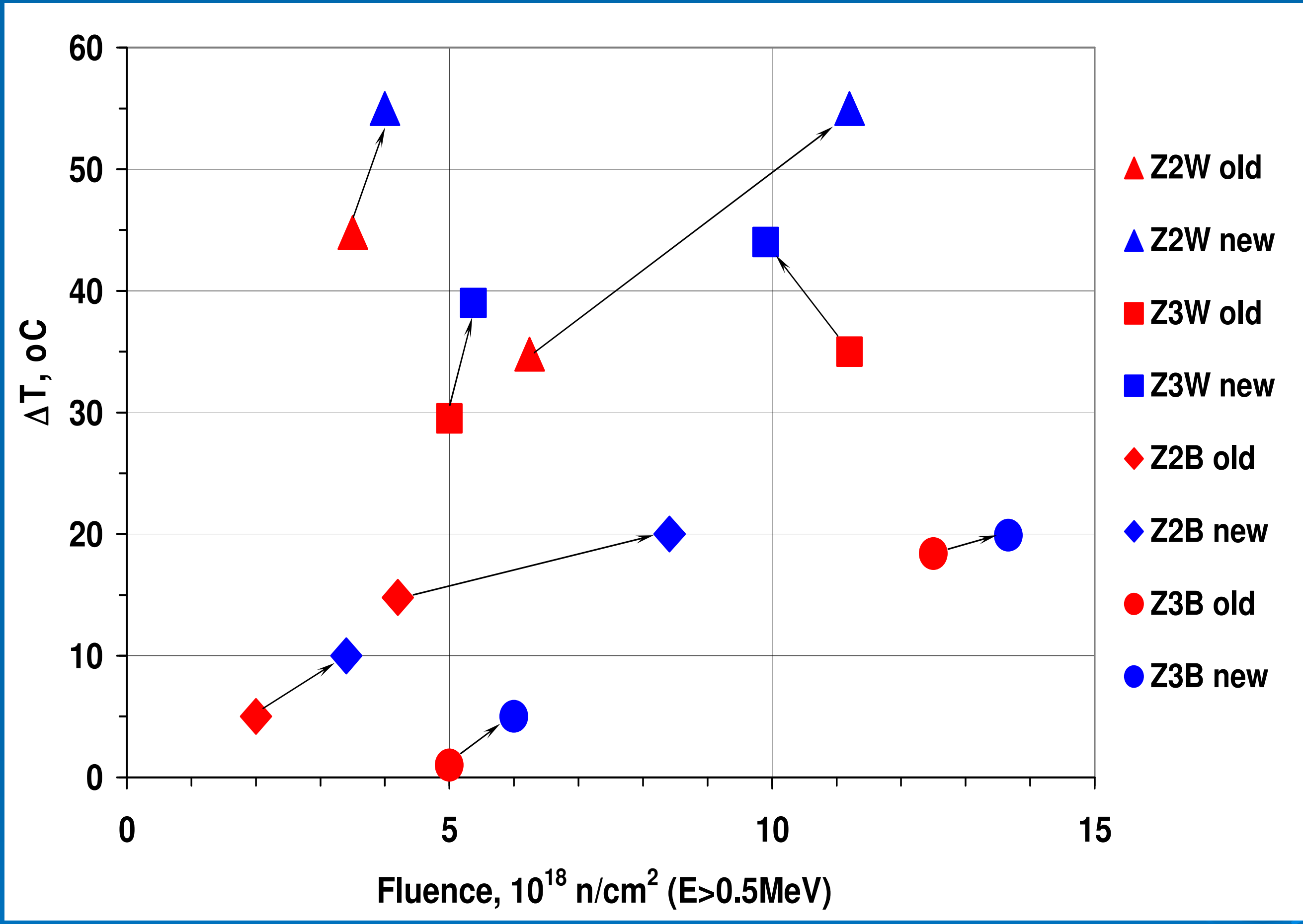




SET		MONITOR					
		^{93}Nb	^{54}Fe	^{58}Ni	^{46}Ti	^{63}Cu	CoAl
●	SCK/CEN WS		✓				
▲	SCK/CEN FDS		✓	✓	✓	✓	
△	KI FDS	✓	✓	✓	✓	✓	✓
▽	KI SDS	✓	✓			✓	
□	KI FNS	✓	✓				

RRC KURCHATOV INSTITUTE

SOME PRELIMINARY RESULTS OF VVER-1000 SURVEILLANCE SPECIMENS TESTING



Z2 – Zaporozhie-2, Z3 – Zaporozhie-3,
B– base metal, W – weld,
old – before fluence reevaluation, new – after fluence reevaluation

RRC KURCHATOV INSTITUTE

CONCLUSIONS